LOCATING UNDERGROUND ROCK OBSTACLES BY ELECTRONICS

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1. GENERAL

1.1 This section provides REA borrowers, consulting engineers, and other interested parties with guideline recommendations on how ripping units and rock units will be determined by the use of seismographic equipment. The use of seismology in buried plant construction should eliminate the confusion that now exists when greater than normal difficulty is encountered during the plowing operation.

1.2 Originally, other methods of defining rock were investigated. One such method was rating tractors and defining their capability to plow or rip through different materials. It was soon learned that there were many variables involved in rating a tractor. Traction methods, accessories allowing plow blades to tilt and vibrate, considerations for the age and general condition of the tractor and the type of environment being dealt with all had to be considered. The amount of variables made it impossible to fairly define the ripping or plowing ability of each tractor.

1.3 Need for a solution to the rock defining problem led to an inquiry into the applications of the seismograph. A seismograph is an instrument used to measure the travel time of a compressional (sound) wave artificially produced in the ground between the source and a detector. Past experience has shown that by using a simple procedure, seismographs can be used to successfully indicate the type and composition of subsurface materials.

1.4 The velocities of seismic (sound) waves differ greatly for different subsurface materials, depending upon such factors as hardness, degree of consolidation and density. The seismograph measures velocity values in each layer of material and thus allows subsurface identification and engineering classification.

1.5 In portions of a project area where there is more than incidental rock, consideration should be given to provide the resident engineer with seismograph equipment. This equipment will be needed to determine if hard ground encountered during the plowing operation is plowable rippable or rock.

2. DEFINITIONS

2.1 Dip - The angle of deviation from the horizontal made by a discontinuity surface. A horizontal discontinuity has a dip of 0 degrees.

2.2 Discontinuity - In reference to actual subsurface structure, the point or depth at which the material composition changes from a harder to softer material, or vice versa. On a plot, the point at which the velocity slope changes value.

2.3 Profile - A cross-sectional representation of the earth surface.

2.4 Survey - The program of conducting a series of seismic traverses to accomplish a specific engineering purpose.

2.5 Time Reading - The measured time of travel of a sound wave through the earth from the hammer to geophone.

2.6 Traverse - A line comprising the geophone position and the hammer stations. More exactly, a sequence of positions in a straight line along the earth's surface, comprising a fixed geophone position and several hammer stations, from which enough time readings can be obtained to construct and interpret one seismic plot.

2.7 Velocity - Speed of sound waves through a particular type of subsurface material. Velocity increases with increasing hardness of

200 to 4600 meters per

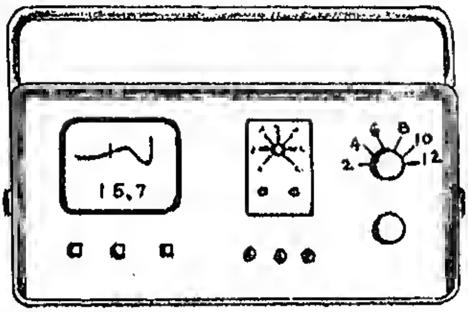
ure 1a) is an electronic

val with very high precision.

The time interval is that required for a sound wave to travel through the earth for a distance of several, tens or hundreds of meters. The sound wave is produced from a hammer blow, dropped weight, or small explosion. The arrival of the sound wave is detected by a geophone.

The total time interval is rarely more than a few hundredths of a second and must be measured to an accuracy of 1/1000 of a second or more, so very precise instrumentation is required. Recent technological advances have allowed units to become more compact, easier to operate and less expensive. Most types weigh several kilograms, depending on the specific model chosen. The type of power source is usually rechargeable batteries.

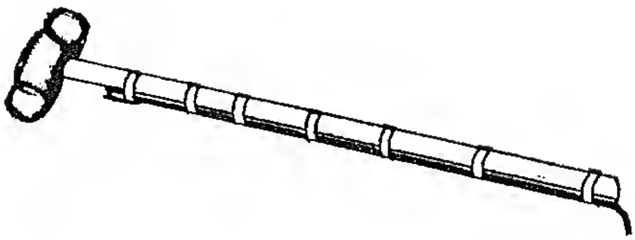
FIGURE 1-A



3.2 Hammer - A sledge hammer (Figure 1b) is all that is required to generate ground vibrations when conducting surveys involving depths at which cables are plowed. The hammer is fitted with a special switch which closes at the instant of impact. <u>Caution should be taken to keep the switch on the upper side of the hammer handle when striking</u>. The hammer switch must be connected through a cable into the seismograph.

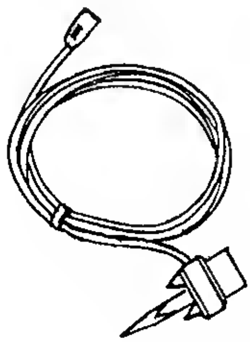
For greater depths of investigation explosives or heavy weight dropping equipment may be used.

FIGURE 1-B



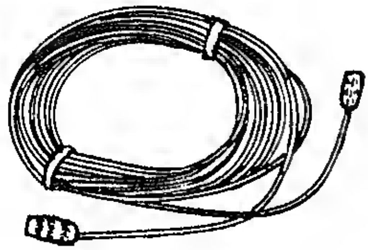
3.3 Geophone - The geophone (Figure 1c) is a sensitive device for detecting the ground vibrations produced by the arriving sound wave in the ground. A spur on the bottom of the geophone allows it to be embedded firmly into the topsoil for maximum effectiveness. The spur may be unscrewed and replaced with a flat base for use on hard topsoil or rock.

FIGURE 1-C



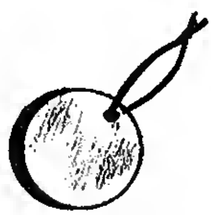
3.4 Hammer Cable - The function of the hammer cable (Figure 1d) is to connect the hammer to the seismograph. Cables are supplied in various lengths, and may be connected in series if additional length is desired.

FIGURE 1-D



3.5 Striking Plate - A striking plate (Figure 1e) should be laid on the ground and used to receive the hammer impact. The purpose of this plate is to achieve maximum energy transfer from the hammer head into the ground. Occasionally, the topsoil may be hard enough that a striking plate is not required.

FIGURE 1-E



The striking plate must be large enough that the hammer energy is not wasted in driving it deep into the soil. On the other hand, it must be small enough to make firm contact with the ground at all points of the plate. A circular plate is recommended in preference to a square plate, because the square plate tends to tip over onto the corners under impact.

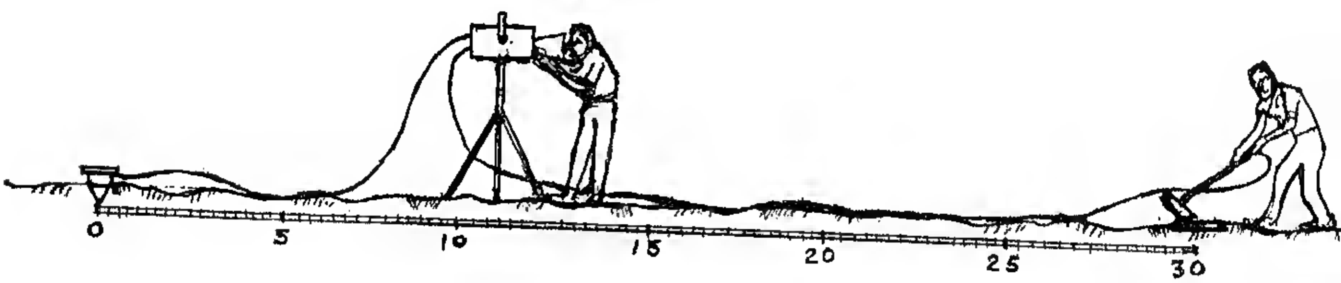
A recommended plate is a circular disc of tool steel, 18 centimeters in diameter and 2 centimeters thick.

4. GATHERING DATA

4.1 The basic Procedure for making a seismic survey is as follows:

1. Connect the geophone and hammer extension cords to the proper receptacles on the seismograph.
2. Lay out a measuring tape along the ground to be surveyed, marking off increments to be used as hammering stations.
3. Place a geophone at the starting point.
4. Turn the seismograph on, adjust the focus and intensity of the reference line on the cathode ray tube, adjust the gain, depress the "clear" function and then depress the "arm" function.
5. Pound a hammer on a striking plate at each marked location (clear and arm each time) and record the corresponding time readings displayed on the seismograph.
6. Plot the data on a time-distance curve.
7. Using either graphical or analytical methods, determine the subsurface composition.

FIGURE II



Note: Maintenance and operating instructions should be followed as indicated by the manufacturer.

5. PRECAUTIONS

5.1 Anchoring the Geophone and Striking Plate - Anchor the geophone firmly in the ground. It is important to establish good coupling between the geophone and the earth. If the soil is dry or loose, or if high wind is present, bury the geophone to a depth of several centimeters and cover it. Avoid placing the geophone in abnormal soil conditions, such as the depression formed by a previous hammer blow. If erratic readings are encountered, experimentation with various geophone placements is recommended. The geophone should not rest on roots or on top of sod. Remove all grass and anchor the geophone in the earth. Normally, the geophone should be anchored in a vertical position (with spur straight down). However, if the distance from geophone to hammer is 1.5 meters or less, or if a high velocity (hard) layer lies within 1/3 to 1 meter of the surface, tilt the top of the geophone 20 - 30 degrees away from the hammer. At larger distances, return it to the vertical position.

5.11 In addition, loose material and grass should be removed before placing the striking plate on the ground, particularly when hammering over large distances.

5.2 Length and Location of Survey Line - The line between the hammering location and the geophone should be centered directly over the place where depth information is required. Avoid topographical irregularities if possible.

5.21 Closer spacing between hammer points and the geophone will yield more accurate and detailed results. The maximum distance from hammer to geophone should be at least 3 to 5 times the desired depth of investigation. For example, if information to a depth of 1 meter is required, the most distant hammer station should be at least 3 meters from the geophone. A distance of 3 to 5 meters is even better.

5.3 Limiting Noise - When taking the actual time readings, it is essential that all noise vibrations be kept to an absolute minimum. The highly sensitive geophone can respond to footsteps, distant machinery and traffic. The only vibrations which can cause trouble are those which exist at the instant of the hammer blow. In working near busy highways, for example, readings should be taken at moments when no vehicles are passing. Under severe conditions of vibration, it may be necessary to carry out the survey at hours when vibrations are minimized, such as evening or early morning. A high level of ground vibration may exist even though the immediate source is not visually apparent.

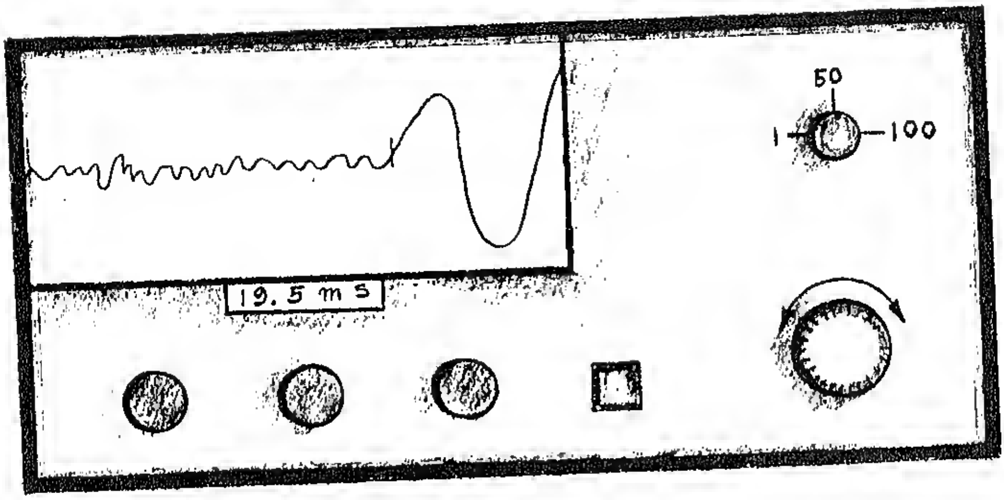
5.4 Generating a Seismic Wave - How successful a seismic wave is transmitted depends on both soil conditions and the method used to generate the wave. Loose soil will absorb much of the hammer energy and prevent the wave from traveling far. Generally, at distances of 6 meters or less, a moderate blow from a 5 kg hammer is sufficient; at larger distances, the operator should strike as hard as possible. The most effective blow is obtained when the striking face falls flat against the striking plate.

5.5 Setting the Gain Control - The function of the gain control is to increase or decrease the amplification of geophone vibrations. As the desired waveform is amplified so is noise. When the gain setting is too low, the wave caused by the hammer blow is not amplified enough to be noticeable. A gain setting too high may amplify noise to such an extent that it is mistaken as the generated seismic wave. For short hammer distances, 3 to 6 meters it is usually sufficient to set the gain control at some intermediate position, such as 3 or 4 on a scale of 10. On seismographs giving a visual display of the seismic waveform the marker used to indicate time readings will bounce up and down on the screen just before hammering, due to surrounding noise. The gain control on this type seismograph should be set such that the marker moves vertically about 0.5 centimeters (for screens 5 to 10 centimeters high). The type of seismograph that gives a digital time readout but no waveform display, will not be discussed here. Refer to a manufacturers instruction manual if information is required concerning non-cathode ray tube type seismographs.

6. DETERMINING THE SEISMIC WAVE TRAVEL TIME FROM A DISPLAYED WAVEFORM

6.1 Example of a typical waveform as shown on a seismograph:

FIGURE III



Turning the marker control knob will cause a marker to move horizontally across the screen. As the marker moves to the right of the screen the time reading increases. Placing the marker at the beginning of the intentionally generated waveform will indicate the time duration taken for the seismic wave to travel from the hammering location to the geophone. The time range of the viewing screen can usually be adjusted by a time period selector knob shown above.

7. PROFILING THE SUBSURFACE

7.1 Knowing the travel time of the seismic wave as well as the distance traveled, we can calculate the wave velocity using the following equation.

$$\text{Velocity} = \frac{\text{Distance}}{\text{Time}}$$

Example: With a 10 meter spacing between the hammering location and geophone and a 2.5 millisecond time reading taken from the seismograph the seismic wave velocity would be:

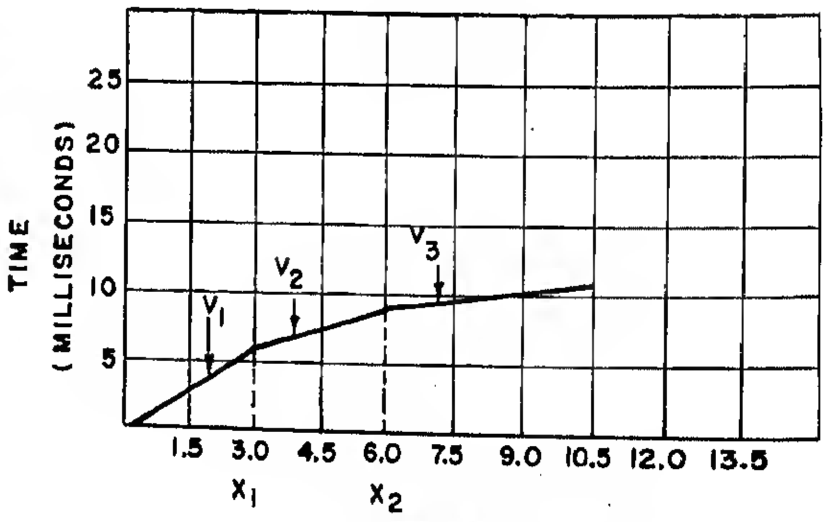
$$\text{Velocity} = \frac{10 \text{ meters}}{0.0025 \text{ sec.}} = 4000 \text{ m/sec}$$

7.2 A single velocity calculation gives a very general indication of subsurface composition. But, in order to get more information several time readings at different distances should be plotted on a graph. Some sample data and a corresponding graph is shown below:

Example:

Distance	Time
0-1.5 meters	2.9 ms
0-3.0 meters	5.8 ms
0-4.5 meters	7.2 ms
0-6.0 meters	8.9 ms
0-7.5 meters	9.5 ms
0-9.0 meters	10.1 ms
0-10.5 meters	10.7 ms

FIGURE IV



7.21 Connecting the points plotted in Figure IV with straight lines yields 3 lines with different slopes. Each slope corresponds to a different velocity and each velocity corresponds to a different subsurface material. The three velocities are as follows:

$$V_1 = \frac{3.0\,\text{m}}{5.8\,\text{ms}} = 517\,\text{m/sec}$$

$$V_2 = \frac{6.0-3.0\,\text{m}}{8.9-5.8\,\text{ms}} = 968\,\text{m/sec}$$

$$V_3 = \frac{10.5-6.0\,\text{m}}{10.7-8.9\,\text{ms}} = 2500\,\text{m/sec}$$

The hammer distances at which the changes in slope occur are designated X_1 and X_2 (see Figure IV). The depth to the first discontinuity (D_1) is:

$$D_1 = \frac{X_1}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}} = \frac{3.0}{2}\sqrt{\frac{968-517}{968+517}} = 0.83\,\text{m}$$

The depth to the second discontinuity (D_2) is:

$$D_2 = P(D_1) + \frac{X_2}{2}\sqrt{\frac{V_3 - V_2}{V_3 + V_2}}$$

For an approximation take:

p = 5/6 or 0.85

For an exact solution take:

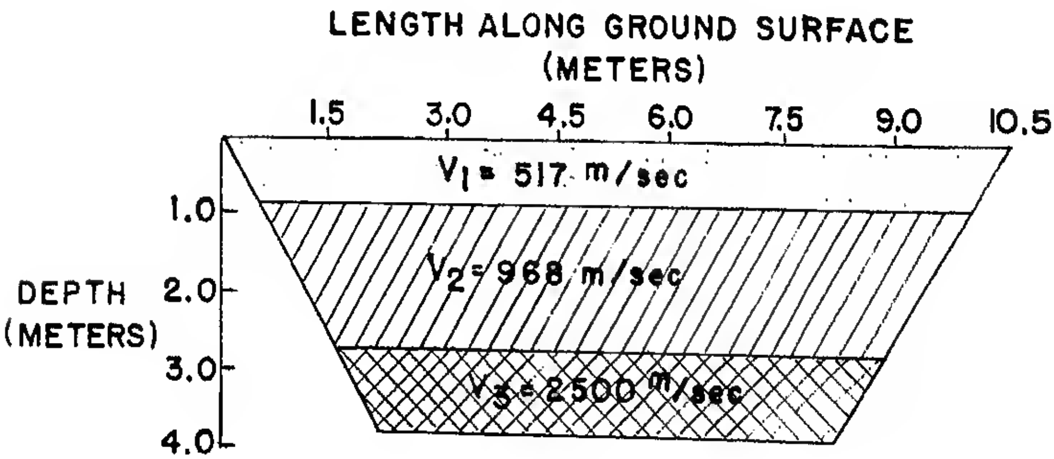
$$P = 1 - \left[\frac{\frac{V_2}{V_1}\sqrt{\left(\frac{V_3}{V_1}\right)^2 - 1} - \frac{V_3}{V_1}\sqrt{\left(\frac{V_2}{V_1}\right)^2 - 1}}{\sqrt{\left(\frac{V_3}{V_1}\right)^2 - \left(\frac{V_2}{V_1}\right)^2}} \right]$$

Substituting appropriate values and approximating, we find:

$$D_2 = 0.85(0.83) + \frac{6.0}{2}\sqrt{\frac{2500 - 968}{2500 + 968}} = 2.70 \text{ m}$$

Based on this data, a rough profile of the area surveyed would appear as shown in Figure V.

FIGURE V



The computed depths represent an average value over the center two-thirds of the entire hammer line. For example, if the hammer line extends to a maximum distance of X max = 100 meters, then the computed depth is an average from roughly the 20 meter station to the 80 meter station.

7.3 In situations not requiring high accuracy an approximation can be used to estimate the depth to which hard materials are not present. Very roughly, we can say that no harder material exists within a depth of at least one-third of the maximum hammer distance. For example, using the plot of Figure IV, we can conclude that there is no material with a higher velocity than V_1 to a depth of at least 1 m (3.0 m/3), no material with a higher velocity than V_2 to a depth of at least 2.0 m (6.0 m/3) and no material with a higher velocity than V_3 to a depth of at least 3.5 m (10.5 m/3). As can be seen, these estimated values differ from the calculated values but, are still reliable enough for many applications.

7.4 Graphical Techniques of Profiling

7.41 At many times while conducting surveys, immediate answers will be needed in the field and calculators will not be available. For this reason, a totally graphical approach to profiling the subsurface will be analyzed in the following paragraphs. The previous example will be used so that results may be verified.

7.42 In order to find the depth of a layer, three points of information must be taken from a graph of time readings versus distance (Figure IV) these are: the velocity through the more shallow material, velocity through the deeper material, and the point along the traverse where the velocity first changes (designated X_1).

7.43 Refer to Figure VI. A line drawn through the velocity V_1 equal 517 m/sec and V_2 equal 968 m/sec indicates a value of R equal to 0.55. The value of 0.55 should be marked off on the second R scale. A line drawn from this point on the second R scale through the critical distance X_1 (in this instance 3.0 meters) yields a layer thickness of 0.80 meters. This is approximately equal to the calculated value.

7.5 Dipping Discontinuities

7.51 Up to this point it has been assumed that discontinuities are horizontal. The fact is each different layer of material is most likely at some incline. To establish the dip of a discontinuity, a traverse must be run in both the forward and reverse directions. Refer to Figure VII. If the geophone was at position A for the first traverse, with the line of hammer stations extending to the right in the sketch, then a second traverse must be taken with the geophone at position B using the same hammer stations.

FIGURE VI

NOMOGRAM FOR MULTI-LAYER SEISMIC REFRACTION INTERPRETATION

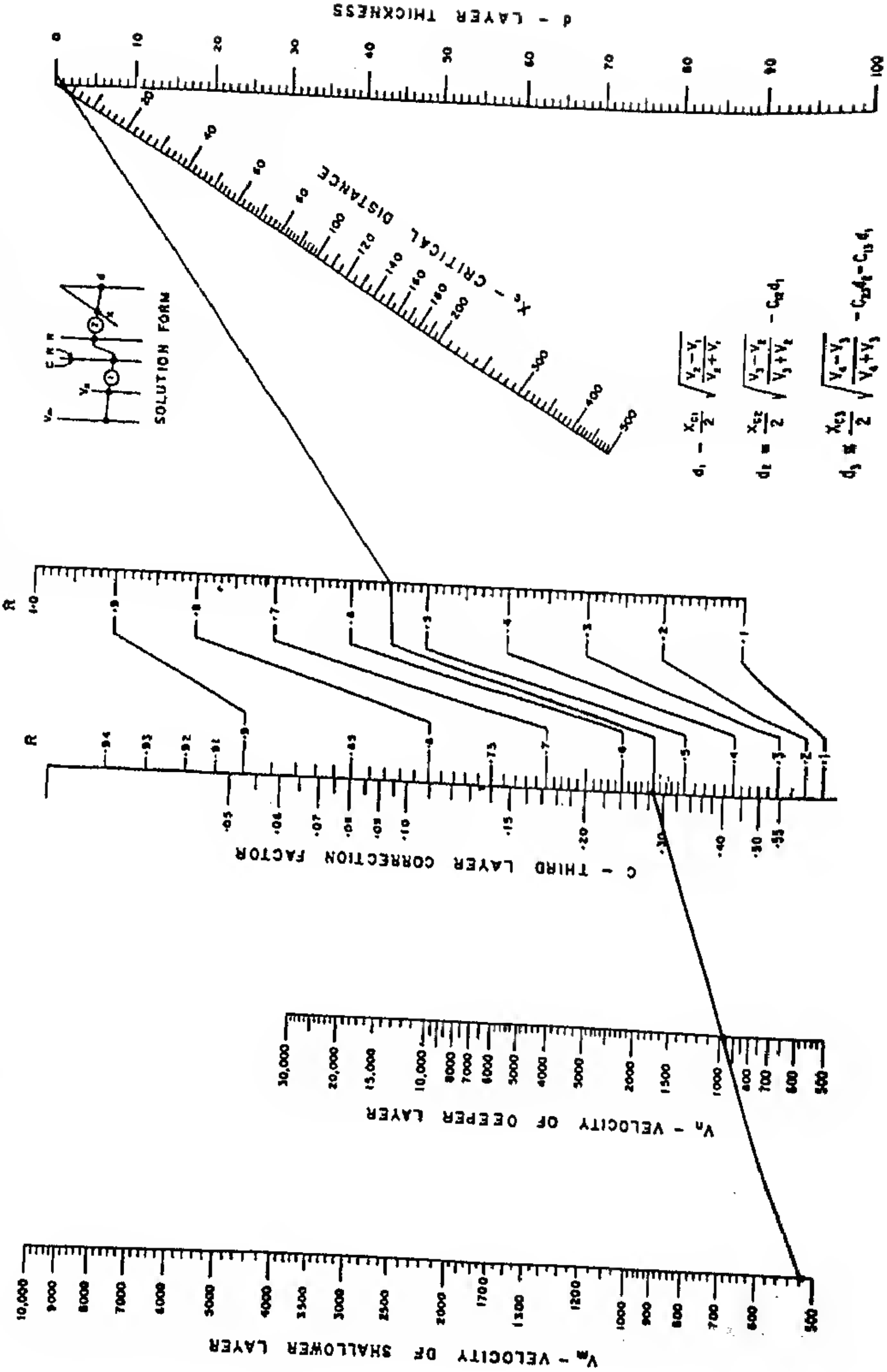


FIGURE VII

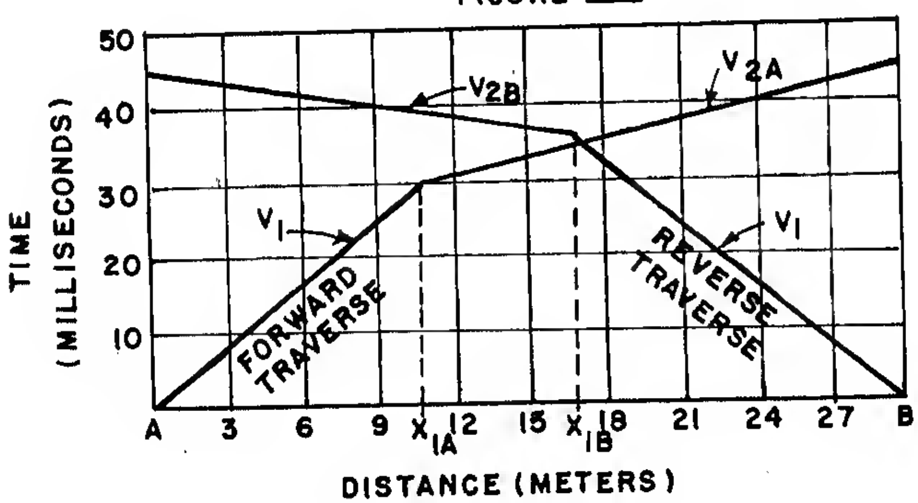
7.52 Taking another example, assume both a forward and reverse traverse were run and data obtained from both traverses was plotted on a graph. See Figure VIII.

V_1 = 360 m/sec.
V_{2A} = 1370 m/sec.
V_{2B} = 2100 m/sec.

Note that the total time from A to B as well as the velocity V_1 must be the same for both traverses. If this is not the case, there is something wrong with the data.

7.53 By inspection of Figure VIII or similar graphs the following conclusions may be drawn concerning the first discontinuity.

FIGURE VIII



a. The depth to the V_2 material will be larger at the end of the traverse which shows the larger break distance, X_1. In this example, X_{1B} (measured from point B) is larger than X_{1A} (measured from point A), so we conclude that the depth at B is greater than the depth at A.

b. Since the dip is proportional to the difference between X_{1A} and X_{1B}, we can make a rough estimate as to whether the dip is large or small. A large difference means a large dip. If X_{1A} and X_{1B} are equal, then the dip is zero and the surface is horizontal.

c. The true velocity V_2 is roughly equal to the average of V_{2A} and V_{2B}.

$$V_2 = 2\frac{(V_{2A})(V_{2B})}{V_{2A} + V_{2B}} = 2\frac{(1370)\ (2100)}{(1370)+(2100)} = 1658 \text{ m/sec}$$

$$D_A = \frac{X_{1A}}{2}\sqrt{\frac{V_{2A} - V_1}{V_{2A}+V_1}} = \frac{10.8}{2}\sqrt{\frac{1370-360}{1370+360}} = 4.1 \text{ m}$$

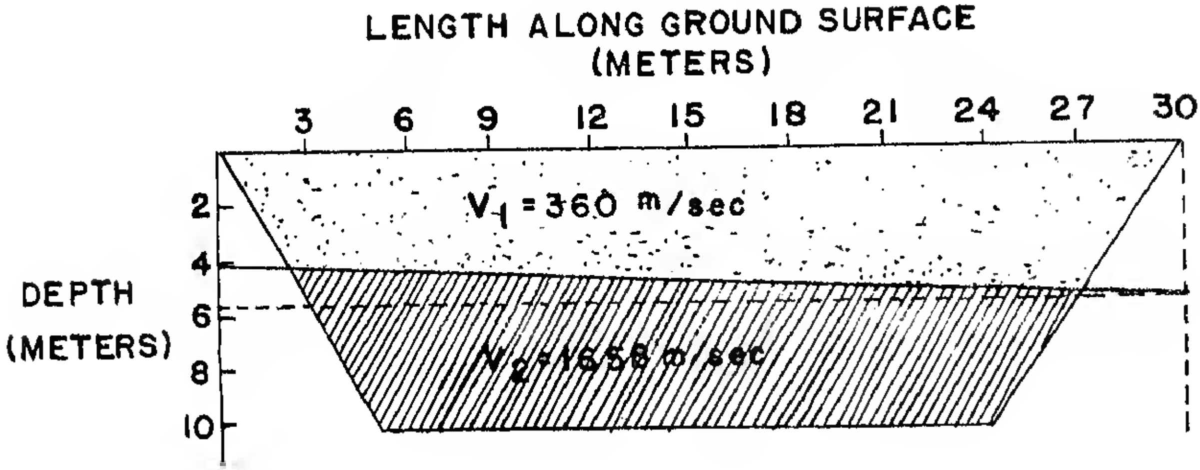
$$D_B = \frac{X_{1B}}{2}\sqrt{\frac{V_{2B} - V_1}{V_{2B}+V_1}} = \frac{13.2}{2}\sqrt{\frac{2100-360}{2100+360}} = 5.6 \text{m}$$

$$\text{DIP ANGLE } \theta = 1/2\left[\sin^{-1}\left(\frac{V_1}{V_{2B}}\right) - \sin^{-1}\left(\frac{V_1}{V_{2A}}\right)\right]$$

$$\text{DIP ANGLE } \theta = 1/2\left[\sin^{-1}\left(\frac{360}{2100}\right) - \sin^{-1}\left(\frac{360}{1370}\right)\right] = 2.7 \text{ degrees}$$

Based on this data a profile of the two earth layers would appear as illustrated in Figure IX.

FIGURE IX



8. <u>ESTIMATING PHYSICAL PROPERTIES OF EARTH MATERIALS FROM SEISMIC VELOCITIES</u>

8.1 After analyzing the seismic graphs, and determining the velocities and depths, proceed to estimate the composition of the subsurface materials from the table in Figure X.

Note: Before attempting to estimate physical properties of the subsurface from the computed velocities, the seismic analyst should familiarize himself with the general nature of the terrain under study. For instance, he should know generally where the area water table is, whether the overburden is a product of weathering or underlying bedrock, whether it is mostly glacial drift over limestone, etc. Velocities alone are not a positive indication of material physical properties.

When estimating the type of subsurface, there are several general rules which the analyst should keep in mind as he studies the velocity chart. These rules are:

1. Velocity is roughly proportional to degree of consolidation, or hardness, of the rock or soil.

2. In unconsolidated materials, velocity increases somewhat with water content.

3. Weathering of a rock will greatly reduce its velocity.

4. A particular rock type will include a range of velocities, and these ranges may overlap for different rock types.

5. Correlation of velocity with the type of earth material will depend to a great extent on the overall geological characteristics of the area under study.

6. Velocity measurements are very sensitive to dip of the interference. If high-precision measurements of velocity are required (for such purposes as estimating rippability under borderline conditions), always assume that a dip exists and follow the procedure for "Dipping Discontinuity" in Section 7.5.

It is entirely possible to use the seismic velocity data to determine such rock properties as rippability and bearing capacity. Such properties may differ with field conditions. Figure XI shows published data on rippability with a D7 tractor.

Figure X

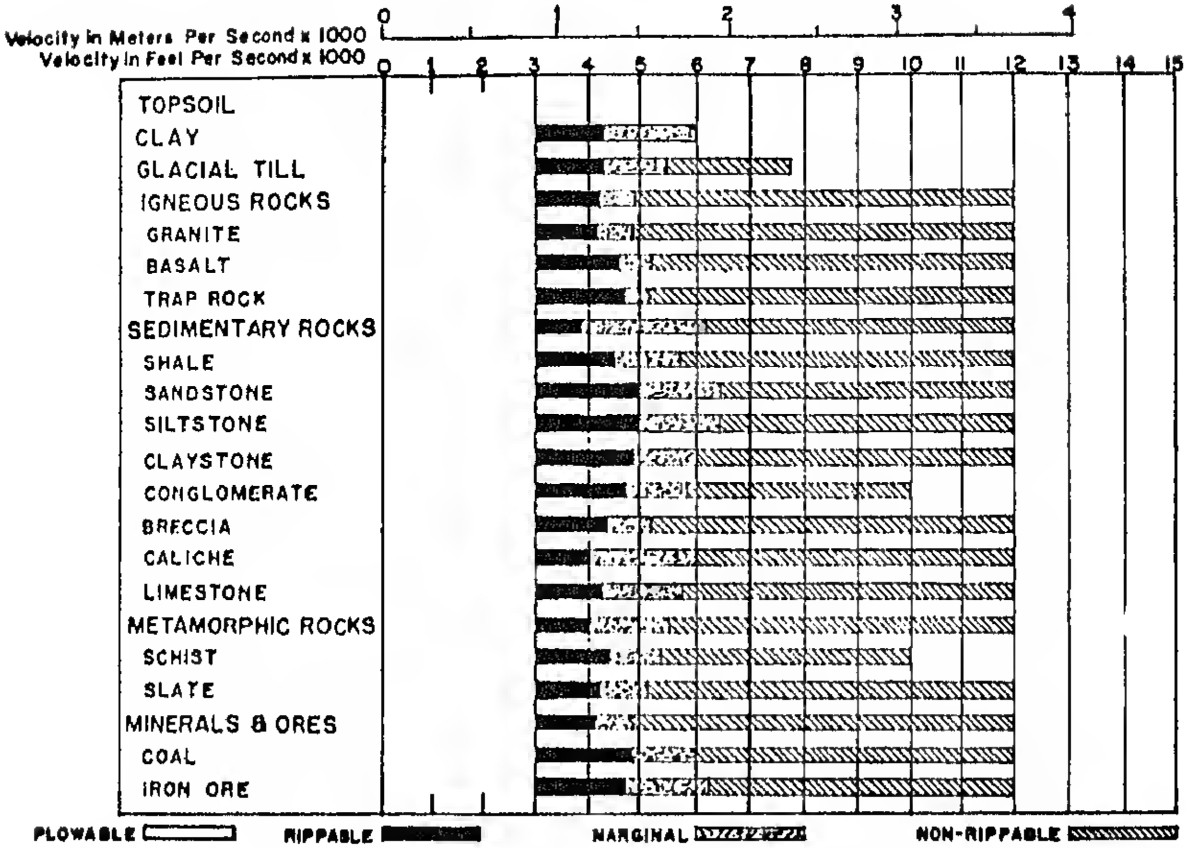
Table of Representative Velocity Values

(Note: Occasional formation may yield velocities which lie outside of these ranges)

	Velocity in Meters/Sec.
Unconsolidated Materials	
Most unconsolidated materials	Below 915
Soil - normal	245 to 460
- hard packed	460 to 610
Water	1525
Loose sand - above water table	245 to 610
- below water table	460 to 1220
Loose mixed sand and gravel, wet	460 to 1050
Loose gravel, wet	460 to 915
Consolidated Materials	
Most hard rocks	Above 2440
Coal	915 to 1525
Clay	915 to 1830
Shale - soft	1220 to 2135
- hard	1830 to 3050
Limestone - weathered	As low as 1220
- hard	2440 to 5485
Basalt	2440 to 3960
Granite and unweathered gneiss	3050 to 6100
Compacted glacial tills hardpan, cemented gravels	1220 to 2135
Frozen soil	1220 to 2135
Pure Ice	3050 to 3660

FIGURE XI

D7G RIPPER PERFORMANCE ESTIMATED BY SEISMIC WAVE VELOCITIES



8.2 Based on the expected plowing and ripping ability of tractors used in the REA program, the velocity ranges below should be interpreted as follows:

Above Water Table	In or Below the Water Table	
0-914 m/sec	0-1524 m/sec	Plowable
914-1524 m/sec	1524-2134 m/sec	Rippable
1524 m/sec and up	2134 m/sec and up	Rock

9. SOIL SURVEY MAPS

9.1 Refer to Appendix B for a list of soil surveys available through the Soil Conservation Service. These surveys provide several kinds of useful information. Depth to rock, gravel or cobble layers, or hard, dense pans are indicated where they are within 2 meters of the surface. Soil surveys also indicate seasonal soil wetness and depth to water table. Corrosivity of soils to steel and concrete is also indicated. Areas of contrasting soils as small as 2 acres are delineated.

Where soil surveys are available, they can be used to select sites where soil properties are most favorable. Once sites are selected soil surveys will indicate the ease or difficulty of excavation and the kinds of soil problems that will be encountered.

APPENDIX A

MOST PROBABLE INTERPRETATION OF TYPICAL DATA PLOTS

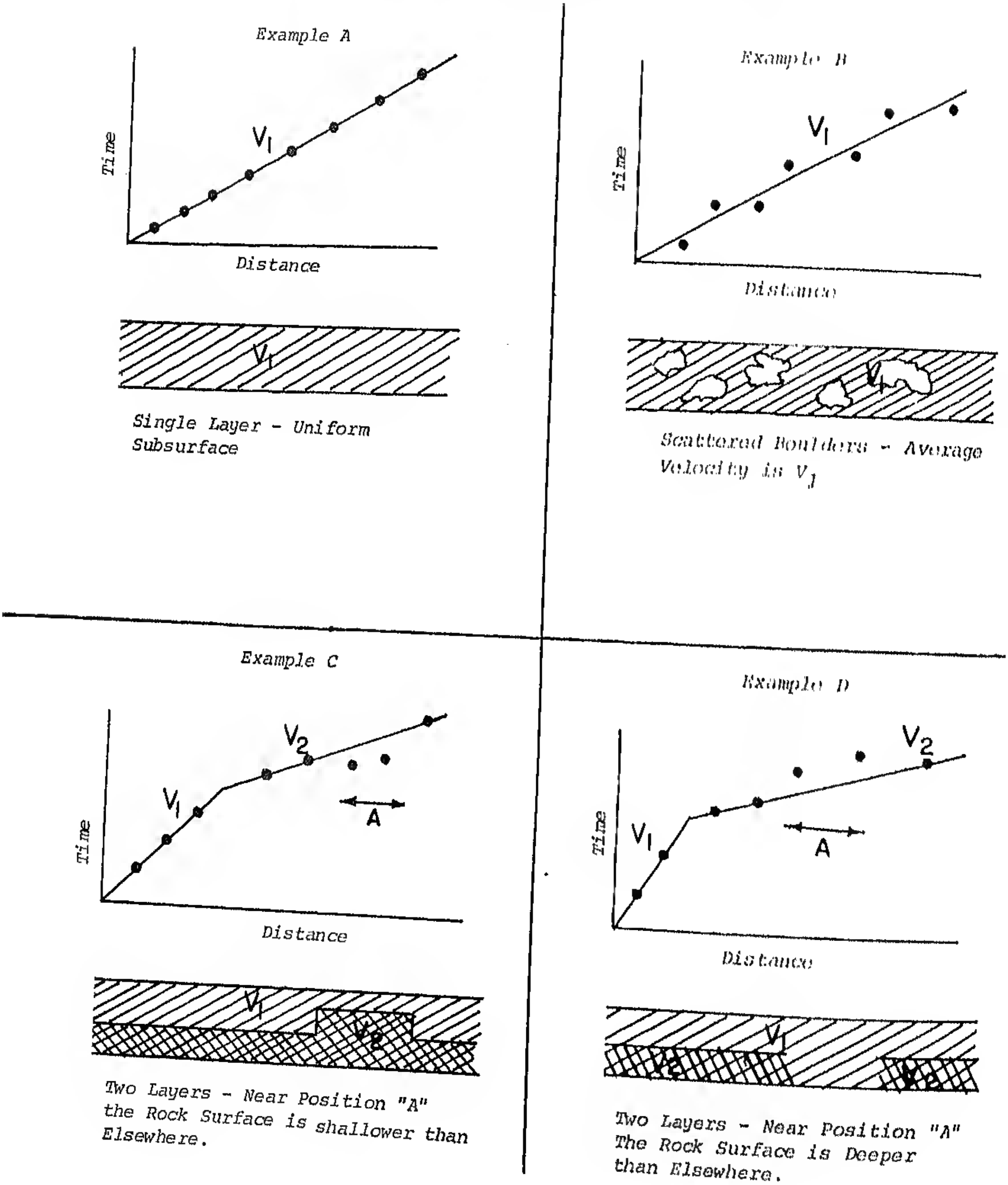
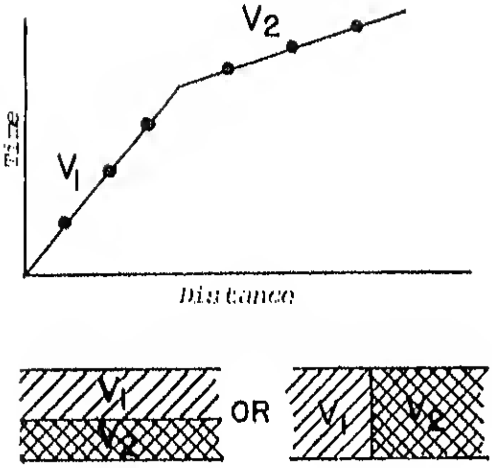


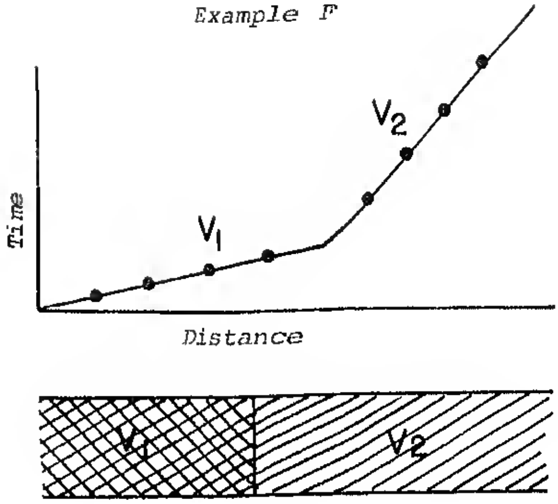
FIGURE I

Example E



Two Layers - The less dense layer on the surface - or - vertical contact of a more dense material in the section farthest from the geophone.

Example F



Two Layers - Vertical Contact of a less dense material in the section farthest from the geophone.